CAUSAL FACTORS OF COLLISIONS AT SEA

Richard Alan Robbins

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

CAUSAL FACTORS OF COLLISIONS AT SEA

by

Richard Alan Robbins

March 1975

Thesis Advisor: R. N. Forrest

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Causal Factors of Collisions at Sea		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; March 1975 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Richard Alan Robbins		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE March 1975 13. NUMBER OF PAGES 49
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Naval Postgraduate School Monterey, California 93940		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Thesis Advisor: R. N. Forrest, AUTOVON 479-2653

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Collisions at Sea

Rules of the Road

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Twenty-two collisions involving United States naval vessels were analyzed in an attempt to discover the principal causal factors of collisions at sea. Collisions involving tactical evolutions, underway replenishment, and evolutions of seamanship, such as mooring to a pier, were excluded from the study.

Several factors including fatigue of the Officer-of-the-Deck and material failure were adjudged not to be significant causal

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601 |
(Page 1)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

factors in collisions. Various factors including time of day, low visibility conditions, and violations of the Rules of the Road were adjudged to be significant causal factors. A Rules of the Road test administered to 14 former OOD's at the Naval Postgraduate School suggests that some naval officers have an insufficient knowledge of the Rules of the Road.

Causal Factors of Collisions at Sea

by

Richard Alan Robbins
Lieutenant, United States Navy
B.S., United States Naval Academy, 1969

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
March 1975

ABSTRACT

Twenty-two collisions involving United States naval vessels were analyzed in an attempt to discover the principal causal factors of collisions at sea. Collisions involving tactical evolutions, underway replenishment, and evolutions of seamanship, such as mooring to a pier, were excluded from the study.

Several factors including fatigue of the Officer-of-the-Deck and material failure were adjudged not to be significant causal factors in collisions. Various factors including time of day, low visibility conditions, and violations of the Rules of the Road were adjudged to be significant causal factors. A Rules of the Road test administered to 14 former OOD's at the Naval Postgraduate School suggests that some naval officers have an insufficient knowledge of the Rules of the Road.

TABLE OF CONTENTS

LIST OF TABLES

I. INTRODUCTION

Collisions at sea cost the United States Navy lives, material, and unfulfilled commitments. As ship units become more costly and the size of the fleet dwindles, collisions will become increasingly costly. A high priority should, therefore, be given to the reduction of occurrence of such collisions. The purpose of this thesis is to determine some of the principal causal factors of collisions at sea involving U.S. Naval vessels and to propose appropriate remedial actions. The analysis of previous collisions at sea is the primary method employed to determine such causal factors.

II. DATA COLLECTION

Twenty-two collisions involving a U.S. Naval vessel were chosen to be investigated in detail. Thirteen of these were taken from Judge Advocate General (JAG) Corps investigative reports on collisions and nine were selected from Combined Case Instructions prepared by the Bureau of Naval Personnel. No JAG report of a collision occurring prior to 1960 was included in the data base and no incident taken from Combined Case Instructions was selected for utilization unless the collision was considered to be of contemporary interest. This was done so that any causal factors evidenced by the data would be pertinent to the Navy of today. All combined case reports of contemporary interest and all JAG reports of collisions which occurred after 1 January 1960 which the author was able to process were utilized if they did not fall into certain special categories described below. This was done to make the data as representative as possible. Excluded from the data base were collisions occurring during naval tactical evolutions, special operations (such as underway replenishment), and evolutions of seamanship, such as mooring to a pier. This was done to make the problem addressed a manageable one.

Hence, the issue under investigation is the causes of collisions suffered by contemporary naval vessels not engaged in the specific evolutions discussed above.

III. DATA EVALUATION

A. DATA EVALUATION OF A SINGLE COLLISION

Before the principal causal factors of collisions could be identified, it was necessary to analyze the collisions in the data base and determine the causal factors responsible for each individual collision. A catalogue of potential causal factors was prepared and as each collision was studied it was determined which of the causal factors was responsible for that particular collision. Although conclusions reached in the JAG investigative reports and in the case studies aided in this process, the assignment of causal factors required the subjective judgment of the author. It should also be remembered that conclusions reached in the JAG investigative reports and case studies were similarly reached in a subjective manner.

The catalogue of potential causal factors which was prepared follows:

I. Violations of the Rules of the Road by U.S. Naval Vessel

   a. Excessive Speed in Fog

   b. Failure to Meet Responsibilities of Burdened Vessel

   c. Improper Utilization of Sound Signals

   d. Other

II. Poor Seamanship

   a. Commanding Officer Performed Unsatisfactorily.

   b. Commanding Officer failed to take timely action with inexperienced officer with the conn.

c. Officer-of-the-Deck Performed Unsatisfactorily.

d. Conning Officer (other than CO, OOD) Performed Unsatisfactorily.

e. Navigator Performed Unsatisfactorily.

f. Executive Officer Performed Unsatisfactorily.

g. Inadequate Support and Recommending by all to CO.

h. Combat Information Center Performed Unsatisfactorily.

III. Shipboard Organization

a. Poorly Trained Bridge Watch

b. Poorly Trained Combat Information Center (CIC)

c. Poorly Trained Navigational Detail

d. Poorly Trained Low Visibility Detail

e. Poorly Trained Engineering Watch

f. Other

IV. Material Failure

a. Due to Improper Use/Operation

b. Due to Improper Maintenance

c. Due to Act of God

V. Weather

a. Sea State

b. Wind

c. Low Visibility

VI. Failure of Other Vessel to Adhere to Rules of the Road

a. Duties of Burdened/Privileged Vessel

b. Excessive Speed in Fog

c. Improper Lighting

d. Other

VII. Other

In addition, for each collision it was recorded whether the collision occurred by day or night, and the time the Officer-of-the-Deck (OOD) and Commanding Officer had spent on deck prior to collision.

B. RESULTS OF EVALUATION OF ALL COLLISIONS

The results of the analysis of all 22 data points appear in Table I. The analysis of issues raised by the data follows the table.

TABLE I: ANALYSES OF COLLISIONS

COLLISION NUMBER	CAUSAL FACTORS																										TIME OF DAY OF COLLISION D=DAY N=NIGHT		TIME ON DECK FOR	
	I				II								III						IV	V			VI						CO	OOD
	a	b	c	d	a	b	c	d	e	f	g	h	a	b	c	d	e	f	a	a	b	c	a	b	c	d				
1			X		X		X					X	X	X									X				1040	D	1 hr.	2 hr.
2			X																				X				0322	N	1	3
3		X	X		X		X					X		X													1936	N	5	1
4	X		X	X	X		X	X				X		X		X						X		X		X	1354	D	1	1
5		X		X	X		X					X		X									X				2145	N	1	1
6	X		X		X		X		X			X		X	X	X						X				X	0717	D	2	5
7	X	X	X				X					X		X								X	X			X	0523	N	2	1
8			X		X		X						X										X				0154	N	1	2
9		X			X		X																				0400	N	4	4
10			X		X		X															X		X		X	0509	N	3	3
11	X		X	X	X		X					X		X								X				X	0509	N	3	1
12	X			X	X		X								X				X			X					2015	N	2	2
13		X					X					X		X													0430	N	1	1
14		X			X		X					X	X	X											X	X	0130	N	0	2
15	X		X				X					X		X								X		X		X	0315	N	1	4
16		X	X				X																				2015	N	1/60	4
17		X	X		X	X	X					X		X									X		X		0426	N	0	1
18			X				X																X			X	0307	N	0	4
19	X				X																	X	X	X			1045	D	3	3
20	X	X	X	X	X																	X		X			2201	N	3	3
21																							X				1517	D	3	3
22		X	X		X			X																			0138	N	8	2

AN "X" INDICATES THAT A CAUSAL FACTOR CONTRIBUTED IN SOME DEGREE TO THE COLLISION ENUMERATED TO THE LEFT.

1. Material Failure

A potential cause of collision is the material failure of some portion of a ship's mechanical or electrical system. In the 22 cases in the data base there is but one instance of material failure contributing to collision. It was one of several causes contributing to collision, and was not the primary causal factor.

In this one incident a provision storeship was proceeding at 11 knots in fog (visibility 300 yards). As defined by Rule 16(a), 11 knots would here be adjudged to be immoderate speed, especially if it were known that other vessels were in the immediate vicinity. A contact was plotted twice on radar and it was ascertained that the contact would have a closest point-of-approach (CPA) of 450 yards. It was known the radar had not been functioning satisfactorily.

The contact then emerged from the fog and collided with the storeship. Later it was ascertained that the radar was indeed defective. To proceed in a thick fog at 11 knots and conclude that the probability of collision is negligible on the basis of two ranges and bearings from even a properly functioning radar is ill advised. Since, in this instance, the ship's radar was suspect, the reliance placed in the sensor was imprudent. The onus of this collision cannot be placed on the ship's equipment but rather on her ship handlers who did not appreciate the equipment's limitations.

Material failure may be discarded as a causal factor of any importance of the collisions in the data base. This is not to say that equipment failure has never been the principal cause of collision or never will be, but rather that the probability that any collision will be caused by material failure is exceedingly small. It should be noted that the collisions dealt with in this study do not include those occurring during special operations such as underway replenishment. Material failure might well be a significant causal factor of collisions occurring during such evolutions.

2. Fatigue of the Officer-of-the-Deck

It has often been hypothesized that a principal causal factor of collisions is an Officer-of-the-Deck (OOD) performing his duties in an excessive state of fatigue with a coincident degraded state of vigilence. To investigate this factor a useful statistic to study would be the hours spent on deck by the OOD prior to collision. This statistic is tabulated in Table I.

To see if there is any upward trend of collision occurrence as the OOD spends more time on watch a Chi-Square test was utilized.

Null hypothesis: Collisions occur with equal probability in each hour of the OOD's watch.

Alternate hypothesis: Collisions do not occur with equal probability in each hour of the OOD's watch.

The mechanics of the test are delineated in Appendix A.

As one would suspect from even a cursory examination of the data, the hypothesis that collisions occur with equal probability during the different hours of the watch was not rejected. Indeed it appears that they occur with remarkable uniformity with time spent on deck by the OOD.

Hence, excessive fatigue of the Officer-of-the-Deck does not appear to be a primary causal factor in collisions. This statement must be qualified in that hours on watch may not be an adequate measure of OOD fatigue. A more meaningful measure of effectiveness, however, could not be retrieved from the data.

3. Day and Night Collisions

It might seem plausible that collisions are more likely to occur in the hours of darkness than in daylight hours. From Table I, it is seen that five collisions out of 22 occurred in daylight, while the remaining 17 occurred in hours of darkness. The Binomial Test is utilized as follows:

Null hypothesis: The probability of a collision occurring during daylight is equal to the probability of collision occurring in the hours of darkness.

Alternate hypothesis: The probability of a collision occurring during the hours of darkness is greater than the probability of a collision occurring in daylight.

For a sample size of 22, the probability of a daytime collision sum equal to or less than five is .008.

Thus the null hypothesis can be rejected with a high degree of confidence. One should also note that on the average the hours of daylight in a day, as defined by this author, generally are greater than the hours of darkness. This would cause the null hypothesis to be rejected with even less trepidation.

If indeed collisions are more likely to occur at night than during the day, there are probably more underlying reasons than simply the absence of the light of the sun. Other important causes might be a decreased lack of vigilance or the absence of the Captain from the bridge. To be more thorough, the preceding binomial test should be applied with all incidents in which visibility was reduced by fog removed from the sample. That is, it is assumed that the presence of fog makes the distinction between daylight and darkness an unimportant one. Now 13 collisions are of interest. Eleven occurred in darkness and two in daylight hours. Applying the same hypotheses as before, it is seen that the probability of two or less daylight collisions occurring under the null hypothesis is .011. Again the null hypothesis is rejected with high confidence.

From the results of the preceding two tests it can be inferred that the probability of being involved in a collision is higher during the hours of darkness than

For a sample size of 22, the probability of a daytime collision sum equal to or less than five is .008.

Thus the null hypothesis can be rejected with a high degree of confidence. One should also note that on the average the hours of daylight in a day, as defined by this author, generally are greater than the hours of darkness. This would cause the null hypothesis to be rejected with even less trepidation.

If indeed collisions are more likely to occur at night than during the day, there are probably more underlying reasons than simply the absence of the light of the sun. Other important causes might be a decreased lack of vigilance or the absence of the Captain from the bridge. To be more thorough, the preceding binomial test should be applied with all incidents in which visibility was reduced by fog removed from the sample. That is, it is assumed that the presence of fog makes the distinction between daylight and darkness an unimportant one. Now 13 collisions are of interest. Eleven occurred in darkness and two in daylight hours. Applying the same hypotheses as before, it is seen that the probability of two or less daylight collisions occurring under the null hypothesis is .011. Again the null hypothesis is rejected with high confidence.

From the results of the preceding two tests it can be inferred that the probability of being involved in a collision is higher during the hours of darkness than

during the hours of daylight. This may seem intuitive, but it might also seem reasonable to assume that the decreased tempo of shipboard routine, to which the Officer-of-the-Deck often unwisely devotes an inordinate amount of time, and the condition of darkness itself would both tend to increase the vigilance of the Officer-of-the-Deck and hence his performance. This is apparently not so.

4. Commanding Officer's Absence from the Bridge

It might seem plausible that a significant causal factor in collisions could be a reluctance by the Officer-of-the-Deck to seek the guidance of his Commanding Officer in a deteriorating situation in which the watch officer either takes a poorly judged action or, what is often worse, fails to act at all. The failure to inform the Commanding Officer is invariably a violation of both Navy Regulations and the Captain's standing night orders.

In the 22 collisions in the data base there are four instances of the Captain either being off the bridge, completely ignorant of the development of a dangerous situation, or, upon being alerted, arriving on the bridge too late to take responsible corrective action. As these incidents were all at night the Officer-of-the-Deck might have been ill-motivated by a desire not to disturb the sleep (often a precious commodity) of his Commanding Officer. In one instance, the Commanding Officer, although advised by his watch officer of a deteriorating situation, failed to take any action whatsoever.

It is instructive to note that three of these four incidents involved a violation of the rules of the road by the other vessel involved in the collision. One might speculate that although these watch officers, or at least three of them, might perform competently in a normal environment, they failed in a situation confounded by the improper action of other vessels.

Since the failure to summon the Commanding Officer or the failure of the Commanding Officer to respond to his watch officer's summons occurred in 19% of the total incidents, one may state that this particular failing had nothing to do with 81% of the collisions. In the collisions in which the Commanding Officers were unable to or chose not to aid their watch officers the principal faults of their vessels were all the failure to meet the responsibilities of the burdened vessel.

It seems probable that had the three aforementioned Captains been advised in a timely fashion of a potentially hazardous situation, they would have taken action to prevent collision. The fourth captain, although possibly extremely fatigued, failed to discharge his responsibilities as Commanding Officer.

Thus while each of these four collisions had an immediate cause, if watch officers had advised their Commanding Officers as they were legally bound to do, or, in the one instance, had the Captain responded to his watch officer's call, then it is possible that the data

base would consist of 18 collisions instead of 22. It may be concluded that the failure of Commanding Officers to advise their watch officers in hazardous situations through their own fault, or more likely, through the fault of the watch officers themselves contributed to a significant number of collisions.

5. Shipboard Organization

A possible contributing factor to collision is the unsatisfactory performance of different segments of the shipboard organization. Inadequate performances by a bridge watch (other than the OOD), Combat Information Center (CIC), navigation detail, low visibility detail, or the main propulsion watch could all increase the probability of collision.

Although bridge watches were found to be ill-trained in three incidents, and the low visibility detail was found wanting in two incidents, these shortcomings had little to do with the collisions which befell the vessels. This is not to say that a bumbling bridge watch or special detail could not be responsible for collision. They simply were not responsible for any of the particular 22 collisions in the data base.

An inadequate performance by a poorly trained Combat Information Center figured in 11 of the collisions. Prior to five of these collisions CIC gave absolutely no recommendations to the Officer-of-the-Deck. In three of these five incidents no surface plot was maintained in CIC.

In six of the cases the recommendations which did emerge from CIC were adjudged to be untimely or of poor quality or both. In one of these six cases no surface plot was maintained in CIC. To make a recommendation to the conn without the aid of a surface plot takes a supremely confident CIC watch officer.

If the CIC's involved in the 11 aforementioned collisions had performed satisfactorily, it is possible that a number of these collisions could have been avoided. Radar has greatly enhanced the ability of watch officers to perceive correctly the exact circumstances associated with their vessel's movement. It is one of CIC's primary missions to utilize this tool to the benefit of the OOD.

The fact that the Combat Information Center failed to perform adequately in 50% of the collisions in the data base is highly significant. Since, hopefully, 50% of naval vessels do not have CIC's which are as poor as those faulted in the data base, it is asserted that a poorly trained CIC will increase a vessel's probability of collision.

6. Weather (Other than Fog)

With the significant exception of reduced visibility due to fog, weather was not a factor in any of the collisions in the data base. That is to say, high winds or a tempestuous sea in no instance reduced a vessel's maneuverability or state of vigilance in such a manner as to contribute to collision.

7. Fog

Nine of the 22 collisions in the data base occurred in an environment in which visibility had been significantly reduced by fog. Thus, while 41% of the collisions occurred in conditions of markedly reduced visibility, certainly the percentage of steaming hours United States naval vessels spend in fog does not approach this high figure. From this one may reasonably infer that the probability of collision, even in this age of radar, increases in fog. While this may seem intuitive, it might also seem intuitive to some that fog would increase a watch officer's vigilance and in turn reduce the probability of collision.

From Table I it is seen that there are nine incidents in which fog significantly reduced visibility. In eight of these instances the naval vessel involved was adjudged to be proceeding at an immoderate speed. In the ninth incident the other vessel was guilty of traveling at an excessive speed, and the major fault of the naval vessel lay in taking improper actions in extremis. In each collision occurring in low visibility at least one of the vessels involved was traveling at an immoderate speed, and in four instances both vessels were guilty of this offense. Clearly there is a significant correlation between the occurrence of low-visibility conditions and the violation of Rule 16(a) of the International Nautical Rules of the Road. Rule 16(a) states: "Every vessel...shall, in fog, mist, falling snow,...or any other condition...restricting

visibility, go at a moderate speed..." "Moderate speed" has been interpreted by the courts as being that speed which would enable a vessel to stop within half the visible distance.

To illustrate the certitude of the preceding argument one may perform a binomial test on the data.

Null hypothesis: The probability of a vessel proceeding at an immoderate speed in reduced visibility when she is involved in a collision is one half.

Alternate hypothesis: The probability of a vessel proceeding at an immoderate speed in reduced visibility when she is involved in a collision is greater than one half.

Sample size is nine. The number of collisions in which the vessel of interest is not proceeding at an immoderate speed equals one.

Under the null hypothesis the probability of observing a value as small as one for the number of vessels not traveling at an excessive speed is .020.

Thus it may be stated that fog increases the probability of collision. With a high degree of confidence it may be stated that ships having collisions during periods of low visibility are much more likely to be traveling at an immoderate speed than not.

8. Failure of Other Vessel to Adhere to the Rules of the Road

The failure of the vessel met by a U.S. naval vessel to adhere to the rules of the road was a significant causal factor in nine of the 22 incidents in the data base. In one of these incidents the vessel encountered failed to perform satisfactorily in a meeting situation, two ships were guilty of proceeding at an immoderate speed in fog (one of which was not sounding fog signals), two vessels failed to meet the responsibilities of the privileged vessel, and four vessels failed to meet the responsibilities of the burdened vessel. Two of these burdened vessels had no lookouts posted and were unaware of the approach of the naval vessel until extremis.

Certainly the rule violations of these vessels contributed in large measure to the resultant collisions. Indeed, in most of these cases these violations were of paramount significance. Yet this is not to say that, if a vessel is encountered on the high seas and she operates in violation of the rules of the road, that one cannot avoid colliding with her. A case in point comes from the data base. In unlimited visibility, during the day, a destroyer encountered a solitary small fishing vessel in a crossing situation. The destroyer was privileged and maintained course and speed until she collided with the fishing vessel, which was incidentally operating

without a lookout. Although the fishing vessel was clearly at fault, this collision could probably have been avoided by the destroyer's action.

The high incidence of, and the nature of the rule violations committed by vessels encountered at sea places this factor high on the list of collision causal factors.

9. Violation of the Nautical Rules of the Road by United States Naval Vessels

In 21 of the 22 collisions in the data base the U.S. naval vessel involved violated at least one of the Rules of the Road. While some of the violations were minor and did not significantly contribute to collision, others were largely responsible for collision.

The gross violations of the Rules of the Road by eight of the nine vessels which experienced collisions in fog have been discussed already. All of these vessels were transiting at an immoderate speed, while some of them were guilty of not sounding fog signals, not posting special low-visibility lookouts, and responding incorrectly upon hearing an uncorrelated fog signal forward of the beam.

In seven of the collisions in the data base the U.S. naval vessel failed to carry out the responsibilities of the burdened vessel. These incidents represent the gravest type of violation.

In 15 collisions the ship's whistle was either not employed when required, or, if utilized, employed incorrectly.

In three instances U.S. naval vessels were privileged when it appeared that the burdened vessel was taking no action to avoid collision. These naval vessels maintained course and speed until in extremis and, emergency maneuvers failing, suffered collisions. Not once either before or during extremis did any of these ships utilize their whistles. The danger signal should certainly have been used to alert the other vessels to the dangers of collision. As it was later ascertained that in two of these collisions no lookouts were posted on the burdened vessels, it seems probable that the timely sounding of the danger signal would have alerted someone on the burdened vessels. Other violations of the Rules of the Road concerning sound signals which are recorded in the data base include the failure to sound fog signals when required, incorrect whistle signals, and the failure to sound signals upon turning and backing.

The aforementioned violations of the Rules of the Road figure in varying degrees in 95% of the collisions under study, and contributed in large measure to 82% of them. The violation of the Nautical Rules of the Road is a highly significant causal factor of collisions.

10. Concomitant Factors

It was of interest to investigate those causal factors which occurred simultaneously with a marked regularity. To this end Table II was constructed. The

entries of this table represent the number of simultaneous occurrences of the factors listed on the horizontal and vertical axes. Given the total number of occurrences of a given causal factor one can then compute the percentage of incidents in which, if a given factor occurred, it was accompanied by another factor. It was hoped some unsuspected relationship between certain of the factors might be revealed.

Many of the inferences made from Table II are simplistic. As one would suspect, it can be seen that, whenever a vessel was adjudged of proceeding at an immoderate speed in fog, conditions of low visibility existed. Also, whenever CIC was cited as performing unsatisfactoriiy it was also deemed to be inadequately trained. Aside from such trivial examples some more interesting pairings are delineated. For example, in those incidents in which naval vessels were adjudged to be guilty of proceeding at an immoderate speed in fog 75% of the vessels also improperly utilized their sound signals. It was also revealed that, when the vessel met by the naval vessel failed to meet the responsibilities of the privileged or burdened vessel, in 78% of the instances the naval vessel improperly utilized her sound signals.

Basically, however, no evidence of unsuspected relationships between causal factors was discovered by this technique. Nevertheless this fact in itself is of some interest.

TABLE II: SIMULTANEOUS OCCURRENCE OF FACTORS

CAUSAL FACTORS																													
		I				II								III						IV	V		VI					
		a	b	c	d	a	b	c	d	e	f	g	h	a	b	c	d	e	f	a	a	b	c	a	b	c	d	TOTAL NUMBER OF OCCURRENCE OF INDIVIDUAL FACTORS
I	a		2	6	4	6	-	6	1	1	-	-	5	-	5	2	2	-	-	1	-	-	8	2	4	-	5	8
	b	2		6	2	7	1	9	-	-	-	-	6	1	6	-	-	-	-	-	-	-	2	3	1	2	5	10
	c	6	6		3		1		1	1	-	-	8	2	8	1	2	-	-	-	-	-	7	6	4	1	7	15
	d	4	2	3		5	-	4	1	-	-	-	-	-	3	1	1	-	-	1	-	-	4	1	2	-	2	5
II	a	6	7	10	5	13	1		1	1	-	-	8	3	8	2	2	-	-	1	-	-	7	5	4	2	5	15
	b	-	1	1	-	1		1	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	1	-	1	-	1
	c	6	9	13	4	13	1		1	1	-	-	11	3	11	2	2	-	-	1	-	-	7	6	3	2	8	18
	d	1	-	1	1	1	-	1		-	-	-	-	-	1	-	1	-	-	-	-	-	1	-	1	-	1	1
	e	1	-	1	-	1	-	1		-	-	1	-	1	1	1	-	-	-	-	-	-	1	-	-	-	1	1
	f	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	g	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	h	5	6	8	-	8	1	11	1	-	-			2	11	1	2	-	-	-	-	-	5	4	2	2	6	11
III	a	-	1	2	-	3	-	3	-	-	-	-	2		2	-	-	-	-	-	-	-	2	2	-	1	1	
	b	3	6	8	3	8	1	11	1	1	-	-		2	11	1	2	-	-	-	-	-	5	4	2	2	6	11
	c	2	-	1	1	2	-	2	-	1	-	-	1	-	1		1	-	-	-	-	-	2	-	-	-	1	2
	d	2	-	2	1	2	-	2	1	1	-	-	2	-	2	1		-	-	-	-	-	2	-	1	-	2	2
	e	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-
	f	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-
IV	a	1	-	-	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-		-	-	1	-	-	-	-	1
V	a	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-		-	-	-	-	-
	b	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-
	c	8	2	7	4	7	-	7	1	1	-	-	5	2	5	2	2	-	-	1	-	-		2	5	-	6	9
VI	a	2	3	6	1	5	1	6	-	-	-	-	4	2	4	-	-	-	-	-	-	-	2		-	-	-	9
	b	4	1	4	2	4	-	3	1	-	-	-	2	-	2	1	1	-	-	-	-	-	5	1		-	3	5
	c	-	2	1	-	2	1	2	-	-	-	-	2	1	2	-	-	-	-	-	-	-	-	1	-		1	2
	d	5	5	7	2	5	-	8	1	1	-	-	6	1	6	2	2	-	-	-	-	-	6	1	3	1		8
		TOTAL NUMBER OF OCCURRENCES OF INDIVIDUAL FACTORS																										
		8	10	15	5	15	1	18	1	1	-	-	11	3	11	2	2	-	-	1	-	-	9	9	5	2	8	

The entries represent the number of times the factors listed on the horizontal and vertical axes occurred simultaneously.

IV. RULES OF THE ROAD TEST

A. RATIONALE

From the study of the incidents in the data base it is seen that in almost every instance the naval vessel under study failed in varying degrees to adhere to the Rules of the Road. In 82% of the collisions the vessel collided with also failed in some manner to abide by the rules.

Since the violation of the Rules of the Road does figure so prominently in collision after collision, one might reasonably hypothesize that United States Navy watch officers are deficient in their knowledge of these nautical rules. To test this hypothesis, a Rules of the Road test was administered to 14 students at the Naval Postgraduate School who had all previously been qualified as and stood watches as Officers-of-the-Deck. The selection of these individuals to the Postgraduate School implies that these officers were superior performers during their prior tours of sea duty.

Eight scenario-type questions were constructed. Each question was to test the respondent's knowledge of a particular segment of the rules. Since the responses were graded in a subjective manner, an effort was made to give a respondent the benefit of the doubt, if by the wording or vagueness of his response, it was not clear whether he

understood the substance and application of the particular rule(s) in question.

The areas of interest which were covered by the questions were: duties and responsibilities of the privileged and burdened vessel, procedures for proceeding in low visibility, meeting vessels encumbered with tows, cross-signals, proper procedures for overtaking and meeting vessels (inland and international), and special operations. Some questions, due to their scenario framework, required a knowledge of a number of the areas. None of the questions dealt with what might be considered esoteric concepts of the minutia associated with the rules and no question required knowledge of any particular signal, light display, etc., which one might claim required special memorization and, if a respondent were indeed at sea, he would have "brushed up" on.

Instead the questions dealt with broad concepts and the most rudimentary knowledge of signaling (i.e., in international waters one short blast means, "My rudder is right.") Although the respondent could, and some did, answer his questionnaire in careful detail, it was not necessary for an individual to do so for him to show an understanding of the basic concepts involved in the questions.

The respondents were asked to complete their questionnaires in one sitting without reference to any material either before or during the period of testing. The concepts

to be tested were, in the author's opinion, so crucial to the proper performance of the duties of the OOD that any individual who was trained at the Naval Academy, Officer Candidate School, or in NROTC, and then subsequently qualified as an Officer-of-the-Deck should have a good untutored working knowledge of them, even though the individual had not been to sea for several years. Therefore, in order not to bias results upward, the condition of no reference was applied to the test. It is believed that 100% of the respondents adhered to the conditions of the test.

B. RESULTS

The following results were obtained by question:

	Concept Tested by Question
Question 1:	Recognition of duties of privileged and burdened vessels.
Question 2:	Proceeding in low visibility.
Question 3:	Meeting a vessel end-on.
Question 4:	Meeting a vessel end-on in low visibility with associated concepts of privileged and burdened vessels.
Question 5:	Meeting a tug and tow.
Question 6:	Recognition of "cross-signals."
Question 7:	Recognition of "cross-signals" and proper procedure for overtaking vessels in inland waters.
Question 8:	Special operations.

The results obtained for each question were:

Question 1: Four of 14 respondents did not indicate that they would have properly carried out the responsibilities incident to the privileged vessel.

Question 2: Two of 14 respondents, upon hypothetically entering thick fog (visibility 300 yards), did not slow to a speed that approached a moderate one. Three respondents did not, upon hypothetically hearing an uncorrelated fog signal forward of their beam, stop their engines and proceed with caution.

As the scenario of this question matured all respondents were placed in extremis. One officer wrote that upon backing he would sound three prolonged blasts (vice three short, of course). This singular gaffe could indicate an ignorance of one of the most rudimentary of nautical rules. Another respondent did not appear to be cognizant of the fact that, if a contact whose speed was 10 knots emerged from fog 300 yards away from him on a collision course, he was indeed in extremis. His response that "slow...and pass astern" of the contact seems to be the acme of optimism.

Question 3: Two respondents upon meeting a contact ahead on a reciprocal course which had shown a small, but steady, left bearing drift, chose to come left and attempt a starboard-to-starboard passage. This action in violation of the Rules of the Road would certainly increase the probability of collision.

Question 4: Eight of 14 responses indicated that the respondents did not realize that vessels "not in sight of one another are neither privileged nor burdened."

Question 5: Eight of 14 respondents thought that a tug with tow automatically becomes the privileged vessel. While the prudent watch officer will exercise great care while maneuvering in the vicinity of vessels encumbered with tows, such vessels do not automatically become privileged in each and every meeting situation. Indeed the responsibilities of the privileged vessel can often be more embarrassing to a

vessel encumbered with tow than the responsibilities attendant on the burdened vessel.

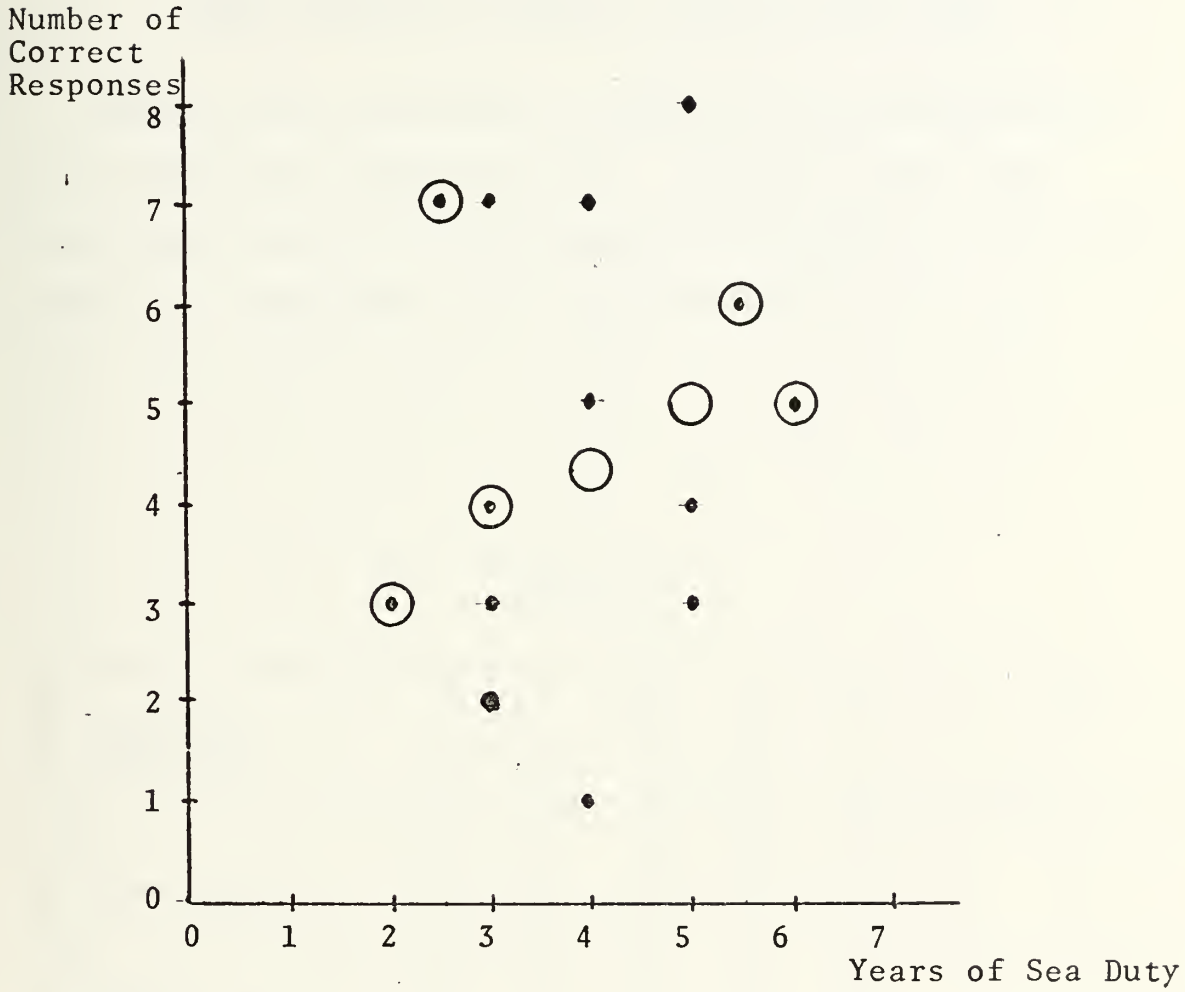
Question 6: Four of 14 officers were not conscious of the illegality of "cross-signals" in inland waters. One of these four did not know the meaning of one and two short blasts as utilized in inland waters. This was one of the grosser errors in a questionnaire which contained major errors in seven of eight questions.

Question 7: This question elicited the largest number of poor responses. Here one had to be familiar with the correct procedure to overtake a vessel in inland waters. Eight of 14 respondents did not recognize the illegality of "cross-signals" in the overtaking situation. Seven of these respondents evidenced a basic ignorance of the proper procedure to be utilized to overtake a vessel. Two officers did not know the meaning of one or two short blasts.

Question 8: Six respondents were not aware of the fact that according to Rule 4(f) of the International Rules of the Road that vessels engaged in special operations become privileged.

A graphic and tabular display of test results versus years of sea duty follows:

CORRECT RESPONSES VERSUS YEARS OF SEA DUTY



An overall upward trend of scores with additional years of sea duty is apparently evidenced above.

MEAN SCORES FOR VARYING YEARS OF SEA DUTY

Mean scores for groups of officers with varying years of sea duty are tabulated below. It can be seen that a better test would have resulted if more officers from each end of the experience scale had been tested.

TABLE III

Years of Sea Duty	2	2.5	3	4	5	5.5	6
Mean Score	3	7	4	4.3	5	6	5
Number of Officers with Respective Years of Sea Duty	1	1	4	3	3	1	1

Overall mean number of years sea duty = 3.93

Overall mean score (number of correct responses) = 4.64

It is of interest at this time to digress somewhat from the thrust of the work and examine the test results in some detail. It might be valuable to see whether officers' knowledge of the Rules of the Road increases with additional sea duty.

A nonparametric examination of this question, utilizing Fisher's exact probability test, is contained in Appendix B. This examination reveals an apparent upward trend of scores with increased years of sea duty. It does seem intuitive that one's knowledge of the rules of the road would increase with additional years spent at sea.

C. CONCLUSIONS DRAWN FROM RESULTS OF RULES OF THE ROAD EXAMINATION

The scores achieved on the Rules of the Road examination were low. From the group of 14 qualified Officers-of-the-Deck, with a mean number of years at sea of 3.93, a mean score of 4.64 correct responses out of eight questions was obtained. Fifty per cent of the naval officers missed at least 50% of the questions. Considering the simplistic nature of the questions, the resultant mean score is far below what might have been expected from a group of professional naval officers. The nature of the errors often displayed a lack of knowledge of the most rudimentary concepts of the nautical Rules of the Road. Among the errors found in the responses were: imprudent and incorrect procedures in fog, the lack of knowledge concerning the

procedures to be utilized upon overtaking and meeting vessels in inland waters (in particular the inability to recognize the illegality of "cross-signals"), and the lack of knowledge of the meaning of the simplest of whistle signals. These errors, if committed on the bridge, could well enhance a ship's probability of suffering collision.

If the results of the examination faithfully reflect the professional expertise of the typical United States naval officer, then it is no surprise that 95% of the vessels in the data base violated the Rules of the Road in such a manner as to contribute to collision. If a much smaller percentage of respondents had scored poorly on the examination, it would have still been a cause for alarm. If only 10% of the Navy's watch officers have an insufficient knowledge of the Rules of the Road, one could surmise that the watch officer qualification process is functioning improperly. This statistic, as reflected by the results of the examination, could be well over 10%.

The results of the testing indicate that some Officers-of-the-Deck are inadequately qualified to stand watch. One must, however, temper this judgment by recalling that the test was conducted in an unrealistic environment by a relatively small number of officers who had not been at sea for some time.

V. REVIEW OF COLLISION CAUSAL FACTORS

The following causal factors and their associated culpability have been scrutinized:

(1) Material failure is not a significant cause of the type of collision studied in this work.

(2) Officer-of-the-Deck fatigue is not a significant cause of collision.

(3) Time of day does affect the probability of collision. Collisions are more apt to occur in hours of darkness than in hours of light.

(4) The absence of the Commanding Officer from the bridge can enhance the probability of collision. The failure of the Officer-of-the-Deck to inform the Captain of a deteriorating situation is generally the cause of this absence.

(5) The failure of Combat Information Center to function satisfactorily as an aid to the Officer-of-the-Deck contributes to significant numbers of collisions. This is especially true at night and in conditions of low visibility.

(6) Foul weather conditions (other than fog) are not a significant cause of collision.

(7) Imprudent action and improper procedure in fog are significant causes of collision.

(8) The failure of vessels met on the high seas to adhere to the Rules of the Road contributes to significant numbers of collisions.

(9) The violation of the nautical Rules of the Road by U.S. naval vessels contributes, in varying degrees, to almost every collision they suffer. Some naval officers appear to have an inadequate knowledge of the nautical Rules of the Road.

VI. CONCLUSION

The vast majority of collisions suffered by United States naval vessels could have been avoided if Officers-of-the-Deck and, in some cases, their Commanding Officers had fulfilled their duties in a competent, professional manner. Both an imprudent disregard for, and an ignorance of, the nautical Rules of the Road figure heavily in many collisions. A Rules of the Road examination administered to qualified Officers-of-the-Deck indicates that there is a serious ignorance concerning the basic precepts of the rules on the part of some naval officers.

In many of the naval ships involved in collision the Combat Information Center functioned poorly as an aid to the ship's conn. The Captain, Officer-of-the-Deck, and other personnel associated directly with the Combat Information Center all are, in varying degrees, responsible for this shortcoming.

Factors such as fog, night time steaming, and the failure of vessels met to adhere to the Rules of the Road all heighten the probability of collision. Yet these factors in themselves do not cause collisions. It is the inadequate response to these conditions by the ship's personnel that causes the collisions.

To prevent the costly collisions of the future, the navy must ensure that its watch officers are ever mindful

of their duties and responsibilities under Naval Regulations and the nautical Rules of the Road. On most of the vessels scrutinized in this study, personnel in key positions were either ill-trained or negligent in the performance of their duties. The Rules of the Road examination indicates that some of the navy's watch officers are ill-trained.

The results of this study indicate that the navy should scrutinize its Officer-of-the-Deck qualification program. Perhaps the instruction received at officer training institutions and the mode of shipboard training and qualification should be scrutinized with an eye to change. Perhaps an annual proficiency examination similar to the naval aviator's NATOPS examination would be in order, or tests such as the Merchant Marine's mate qualification examinations might be instituted. A detailed study of these alternatives is beyond the scope of this thesis. The surest way, however, to prevent the collisions of tomorrow is to initiate higher standards of professional competence for the officer corps today.

APPENDIX A

CHI-SQUARE TEST CONCERNING FATIGUE OF OFFICER-OF-THE-DECK

From the data base the following table was constructed:

Hours on watch for OOD	1	2	3	4 and over
Number of collisions in corresponding hour of watch	7	5	5	3

The above table is suspect in that several of the "time-on-deck" statistics were conjectures from the incident reports, and thus represent "best guesses" rather than figures that can be accepted with certitude.

To test the null hypothesis the Chi-Square one-sample test is utilized.

$$\chi^2 = \sum_{i=1}^{4} \frac{(O_i - E_i)^2}{E_i} \text{ , degrees of freedom = 3}$$

where:

O_i = Observed number of collisions in $i^{\underline{th}}$ hour,

E_i = Expected number of collisions in $i^{\underline{th}}$ hour under null hypothesis,

$E_i = 22/4$, $i = 1, 2, 3, 4$.

Hence $\chi^2 = .545$.

From Table C, Appendix I, of Fisher we see that if the null hypothesis is true, then a Chi-Square statistic equal to or less than .545 has a probability of occurrence of at least .90. Hence the null hypothesis is not rejected.

APPENDIX B

A NONPARAMETRIC EXAMINATION OF THE ISSUE OF WHETHER KNOWLEDGE OF THE RULES OF THE ROAD INCREASES WITH ADDITIONAL YEARS OF SEA DUTY

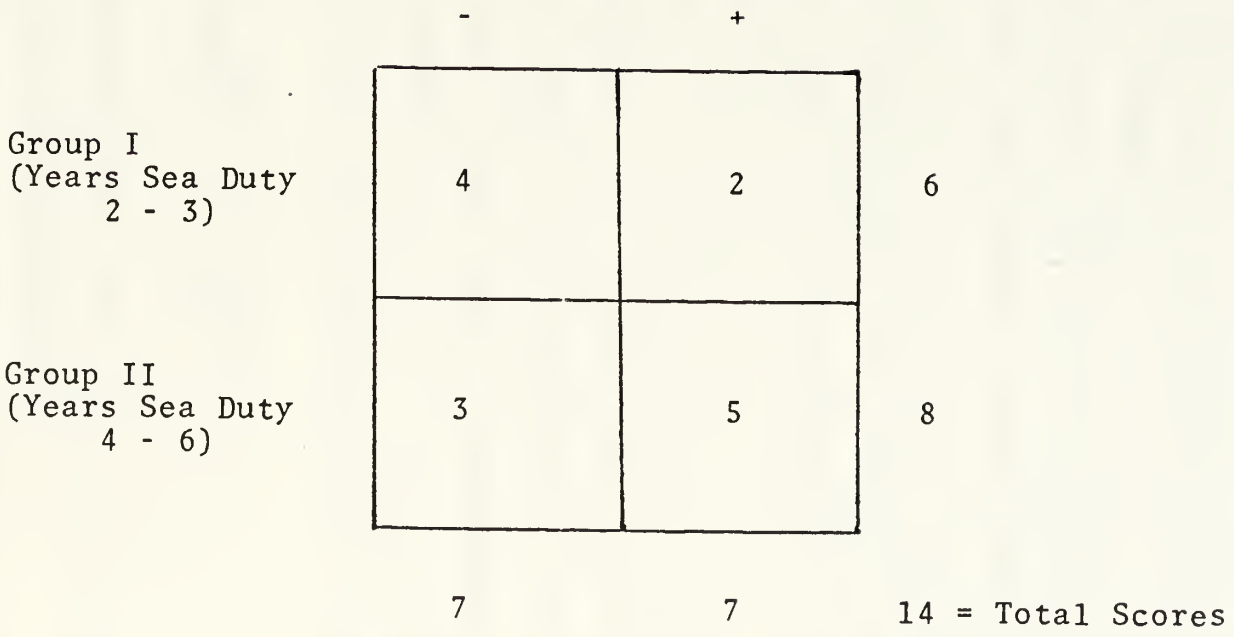
Page 44 shows a tabulation of each respondent's score and years of sea duty, and page 45 contains a Fisher Exact Probability Test contingency table.

TABULATION OF EACH RESPONDENT'S SCORE AND YEARS OF SEA DUTY

Years of sea duty	6	5-1/2	5	5	5	4	4	4	3	3	3	3	2-1/2	2	
Score	5	6	8	4	3	7	5	1	7	4	3	2	7	3	Mean = 4.64
Score Relationship to mean	+	+	+	-	-	+	+	-	+	-	-	-	+	-	+ = score above mean - = score below mean

Median Score = 4.5

A FISHER EXACT PROBABILITY TEST CONTINGENCY TABLE



The Fisher Exactly Probability Test is a nonparametric technique used to analyze discrete data when data points (scores here) are from two independent samples which are small in size. These scores must fall into one of two mutually exclusive categories.

The null hypothesis is that the scores from Groups I and II do not differ significantly in the proportion with which they fall above or below the overall mean score. Group I consists of individuals with from two to three years of sea duty, and Group II of individuals with from four to six years of sea duty.

The probability of obtaining test results under the null hypothesis as extreme or more extreme than the observed outcomes is .296. Using Tocher's modification the probability of cases more extreme than the observed one is utilized. This probability is .051. If a confidence level of $\alpha = .1$ is used, the following ratio is obtained:

$$\frac{\alpha - .051}{.245} = \frac{.1 - .051}{.245} = .2$$

where .245 is the probability under the null hypothesis of the occurrence of the observed outcome.

A table of uniform random numbers (0 to 1) was utilized to obtain a random number. If the number drawn had been less than .2 the null hypothesis could have been rejected. Since .36063 was drawn the null hypothesis cannot be

rejected at $\alpha = .1$ even though Tocher's modification makes the Fisher Exact Probability Test less conservative.

Thus we cannot reject the hypothesis at our selected level of confidence ($\alpha = .1$) that there is no significant difference in the scores attained on the Rules of the Road test by the groups of officers with different levels of experience. There is, however, an apparent upward trend of scores with increased years of sea duty. It seems intuitive that, in most cases, one's knowledge of the Rules of the Road increases with additional years spent at sea.

BIBLIOGRAPHY

1. Bureau of Naval Personnel, Combined Case Instructions, Cases 1 through 50, NAVPERS 10489, 1963.

2. Noel, J. V., Watch Officer's Guide, 9th ed., United States Naval Institute, 1968.

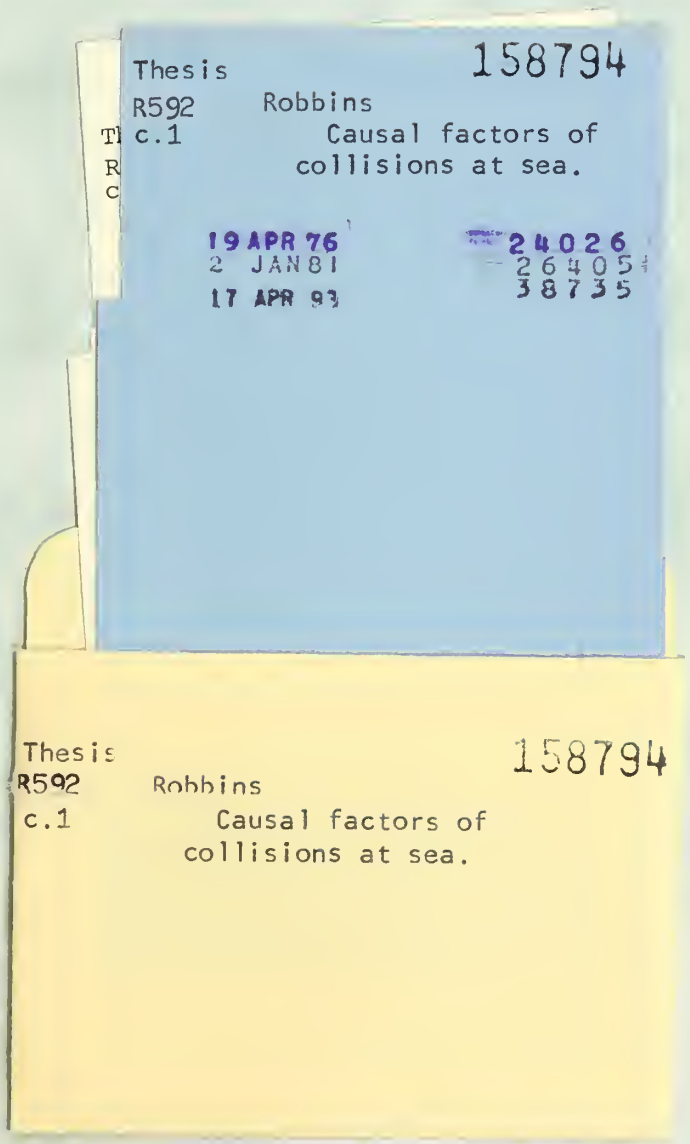
3. A Seaman's Guide to the Rules of the Road, United States Naval Institute, 1971.

4. Siegel, S., Nonparametric Statistics, McGraw-Hill, 1956.

5. United States Coast Guard, Rules of the Road International-Inland, CG-169, 1965.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Department Chairman, Code 55 Department of Operations Research/Systems Analysis Naval Postgraduate School Monterey, California 93940	1
4.	Curricular Officer, Code 30 Department of Operations Research/Systems Analysis Naval Postgraduate School Monterey, California 93940	1
5.	Commanding Officer Naval Safety Center Naval Air Station Norfolk, Virginia 23511	1
6.	Commanding Officer Surface Warfare Officers School Command Newport, Rhode Island 02840	1
7.	Professor R. N. Forrest, Code 55 Fo Department of Operations Research/Systems Analysis Naval Postgraduate School Monterey, California 93940	1
8.	LCDR R. J. Bedow, USN, Code 55 Bi Department of Operations Research/Systems Analysis Monterey, California 93940	1
9.	Chief of Naval Personnel ATTN: PERS 11B Department of the Navy Washington, D. C. 20370	1
10.	LT Richard Alan Robbins, USN 501 Sunset Lane Hot Springs, Arkansas 71901	1



Thesis 158794
R592 Robbins
c.1 Causal factors of
collisions at sea.